Personal Communications Via Present and Future Satellite Systems

A. E. Williams, R. K. Gupta, and A. I. Zaghloul

Satellite and Systems Technologies Division
COMSAT Laboratories, Clarksburg, MD 20871 USA

ABSTRACT

Personal communications satellite systems are designed to provide narrowband voice service directly to a handheld transceiver no larger than a cellular phone. For the past 5 years, extensive studies have been undertaken by industry to determine whether operation into a handheld terminal can be achieved more successfully via communications satellites in low earth orbit (LEO), intermediate circular orbit (ICO), or the more conventional geostationary orbit (GEO). Systems based on these three orbit types have been proposed and are in various stages of construction, with initial deployments scheduled during the years 1998 to 2000. This paper gives an overview of proposed personal satellite communications systems, describes their current status, and offers a perspective on how these systems might evolve in the marketplace in the post-2000 time frame.

INTRODUCTION

The concept of personal communications via satellite has evolved from highly successful fixed point-to-point geostationary systems such as INTELSAT, as well as from the Inmarsat system which currently provides communications using four Inmarsat-2 geostationary satellites transmitting global beams with EIRP's of 39 dBW to stabilized maritime and land antennas as small as suitcase terminals. A new series of higher powered satellites with EIRP's of 48 dBW—the Inmarsat-3's, due to be launched in the first half of 1996—will exploit spot beams to provide service to terminals as small as laptop computers. Figure 1 illustrates the trend in terminal size reduction from the 1–1.5 m maritime and land terminals to the suitcase size terminal and the recently announced mini-M laptop terminal to be marketed as Planet 1. In addition, many regional systems such as those in Mexico, Australia, Europe, North America, and India, provide communications to small mobile terminals.

The introduction of small portable laptop size personal communication terminals by COMSAT using the Inmarsat 3 satellites can be considered the precursor to systems which can communicate directly with cellular type handheld telephones. In 1990 Motorola took the lead by announcing a system of LEO satellites that would provide spot beams on the earth's surface powerful enough to close a voice channel link with a handheld transceiver. This announcement initiated a flurry of activity in the communications and satellite industries, resulting in a large number of additional satellite systems being proposed (see Table 1), ranging from LEO, to ICO, to GEO systems. This paper presents and compares the important technical, operational, and business characteristics of these personal satellite communications systems.

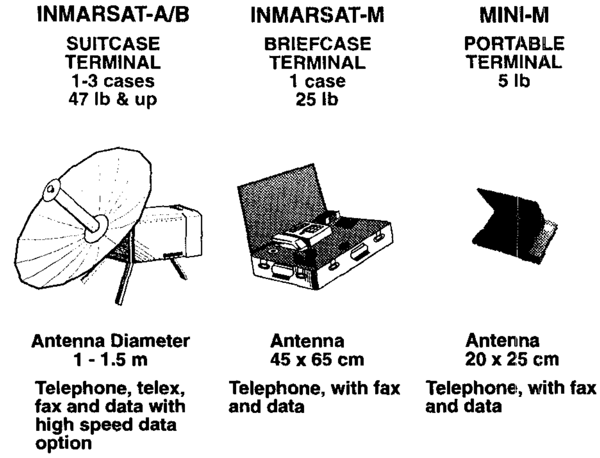

Fig. 1. Inmarsat Terminal Size Trend

SATELLITE DESIGN

A schematic of a personal communications satellite is shown in Figure 2. The feature common to systems for all three orbit types is a satellite repeater that provides connectivity between the earth station (public switched telephone network) and handheld transceivers. Connectivity is furnished through earth-station-to-satellite feeder links, which operate in the C-, Ku-, or Ka-frequency bands, and through satellite-to-handheld transceiver mobile links, which consist of a set of high-gain contiguous spot beams operating at either L- or S-band frequencies. Reuse of the mobile spectrum in the spot beams permits expanded

0-7803-3246-6/96/$5.00

Table 1. Existing and Proposed Mobile Communications Satellite Systems

MOBILE SATELLITES	NO. OF SATS	ORBIT	OPERATIONAL DATE
Existing Systems			
Inmarsat 2/3	4/5	GEO	1976/96
Optus B1	2	GEO	1992
Solidaridad	2	GEO	1994/5
AMSC	2	GEO	1996
INSAT	2	GEO	1996
Proposed Handheld			
Iridium	66	LEO	1998
Globalstar	48	LEO	1998
Oyssey	12	ICO	1999
ICO-global	10	ICO	1999–2000
Ellipsat/Ellipso	24	LEO/ Ellip.	1999
CCI	40	LEO	1999
Celstar	2	GEO	1999
SatPhone	2	GEO	1998
ACeS	2	GEO	1998
APMT (China)	2	GEO	1998
Agrani	2	GEO	1998
African	2	GEO	1998

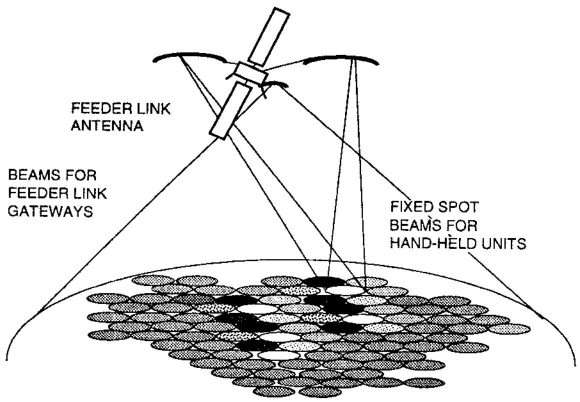

Fig. 2. A Personal Mobile Communications Satellite

communications bandwidths (and large numbers of voice channels). In general, the satellite resources and designs are dominated by the mobile links, whose design in turn depends on several key technical assumptions regarding such factors as orbit type, margins, channel bandwidth, modulation access, and transceiver characteristics.

- ***Coverage vs Number of Satellites.*** Complete coverage of the earth's surface is achieved only with a system of non-geostationary satellites. The minimum number required for a given orbital height vs user elevation angle is shown in Figure 3, and the number of orbital planes, and satellites per plane, are shown in Figure 4 [1]. Geostationary satellites do not provide coverage at high latitudes, and present systems under consideration such as, Agrani and ACeS, are for regional use. Nevertheless, since most of the earth's population resides at lower latitudes, a 4-satellite GEO system can be considered 'approximately global.'

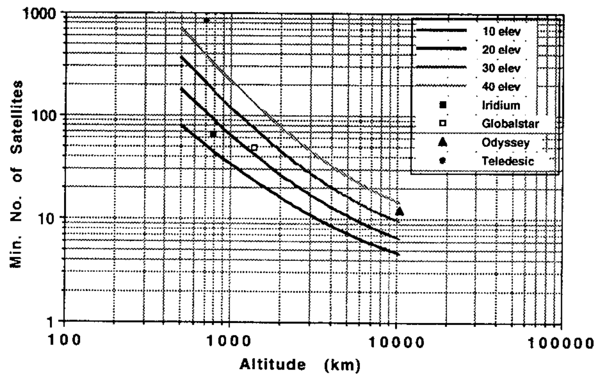

Fig. 3. Number of Orbiting Satellites vs Orbital Height

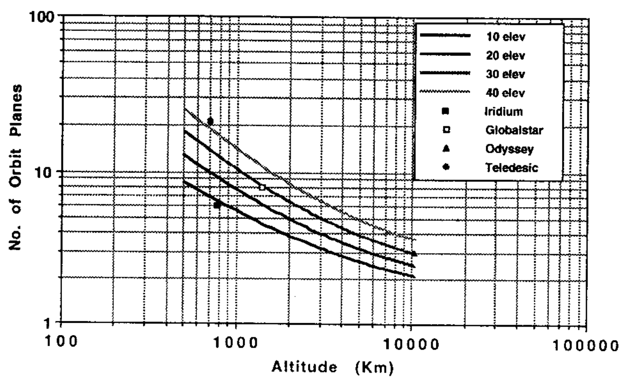

Fig. 4. Number of Orbit Planes vs Orbital Height

- ***Mobile Frequencies and Propagation Margin.*** Three transmit/receive frequency bands are available (1.5/1.6 GHz, 1.6/2.4 GHz, and 2/2.1 GHz), with approximately 30 MHz of bandwidth at each frequency. While the mobile frequency allocation is a basic requirement, the key to establishing a successful link is to have the margin necessary to provide reliable communications in an environment where signals may vary rapidly due to shadowing and multipath. In addition, the link must be designed at the worst-case user elevation angle and beam edge. For example, the Iridum mobile links are designed for 16.5 dB of margin, while the ICO-global links are based on 10 dB—although the latter system uses satellite diversity to enhance communication performance.

- ***Channel Bandwidths and Modulation Access.*** Current bandwidth reduction techniques permit satisfactory voice quality to be achieved for bit rates down to 2.4 kb/s. Nearly all the proposed systems are baselining 4.8 kb/s, with the possibility of expanding capacity by moving to the lower bit rates. It is worth noting that each voice channel must be provided with an encoder at the sending end and a decoder at the receiving end of the link, and that each process adds about 20 ms to the transmission delay. Therefore, subjective effects of the transmission delay difference between the LEO and GEO systems is not nearly as great as would be expected from the basic transmission delay. Access techniques such as code-division multiple access (CDMA) in Odyssey and Globalstar, or time-division multiple access (TDMA) in ICO-global and Iridium, have been proposed. Both have advantages and disadvantages. For example, CDMA can perhaps tolerate more interference; however, designed system capacity can be realized only with accurate power control, and handsets require the use of lossy diplexers.
- ***Transceiver Characteristics.*** As a terminal no larger than a state-of-the-art cellular telephone, the transceiver must embody a number of (in some cases conflicting) characteristics: low power, light weight, long battery life, and a compact antenna design. Typical parameters are given in Table 2.

Table 2. Typical Handset Characteristics

Average Power	<250 mW
Weight	<100 g
Volume	No larger than cellular
Antenna Gain	0–2 dBi
G/T	≥ -25 dB/K
Long Battery Life	>4 hr talk time, 24 hr

SYSTEM DESIGN

The general design methodology for personal communications satellite systems is shown in Figure 5. The satellite design follows largely from the mobile link budgets, and the system design from the coverage and associated network infrastructure. However, the technical design must be matched by the market and the overall system business structure. As the methodology shows, this is an iterative process which brings together both technical and market data in order to determine the system's financial performance.

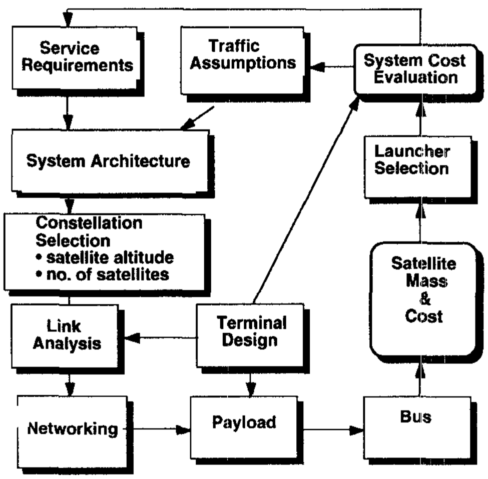

Fig. 5. Design Methodology

- ***Technical.*** Since the handset must have low power and antenna gain, the only way to close the return mobile link is to provide the necessary gain on the satellite antenna. This, then, determines the antenna aperture, as well as the size and number of the spot beams. Figure 6 compares these parameters for the three orbital candidates. Note that these values are highly dependent on link margin. With the antenna size and use of the spot beams set by the critical return link, the satellite RF power per carrier necessary to close the forward mobile link can be determined. This in turn provides the major contribution to satellite DC power and mass. Figure 7 compares the ranges of satellite power and mass for the three different orbit types.
- ***Financial.*** System costs are derived from the cost of the satellites, the number of satellites, the launch cost estimates, and the network costs necessary to support the overall communications system. Extensive studies at COMSAT have yielded estimated costs for the three

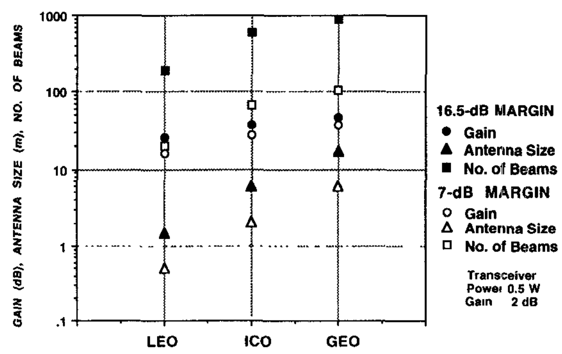

Fig. 6. Antenna Aperture and Number of Spot Beams for LEO, ICO, and GEO Satellites

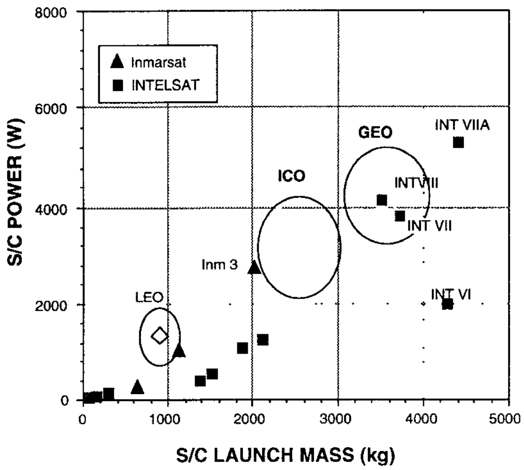

Fig. 7. Mass/Power for LEO, ICO, and GEO Satellites

orbital systems ranging from 1 to 4 billion dollars. Costs for LEO systems are the highest, and decrease as orbital height increases. However, this represents only one side of the business equation. The other side, which is much more difficult to assess, is related to market size, capacity growth rate, and the per-unit user charges. Wide variations in these parameters can significantly distort the financial rate of return and the overall business assessment.

- ***System Comparisons.*** Table 3 summarizes and compares the important characteristics of the three orbital systems. Parameters such as system cost, satellite lifetime, and market size and growth play important roles in this comparison, while round-trip delay, availability, handover, and handset characteristics are critical factors in the utility of the system, and consequently its market acceptance.

CONCLUSIONS

This paper has examined the important system parameters of the personal satellite communications systems scheduled for deployment in the 1998–2000 time frame. Technical and system costs can be compared by examining a generic design; however, business performance is more dependent upon market judgment. How will the business plans of systems such as Iridium and ICO-global be affected by the cheaper GEO regional systems? If the simpler regional systems such as Agrani and ACeS reach the marketplace first, will this cause a significant distortion of global market estimates? What does seem clear is that satellite personal communications systems provide a niche that is complementary to land-based cellular systems, and that at least two or three systems should prove commercially viable. Which systems, and the exact mix of these systems, will clearly be decided by the market.

Table 3. Personal Communications Satellite System Characteristics

CHARACTERISTIC	LEO	ICO	GEO
Space Segment Cost	Highest	Medium	Lowest
System Cost	Highest	Medium	Lowest
Satellite Lifetime, Years	5 to 7	10 to 12	10 to 15
Terrestrial Gateway Cost	Highest	Medium	Lowest
Overall System Capacity	Highest	Medium	Lowest
Round-Trip Time Delay	Medium	Medium	Longest
Availability/Elev. Angles	Poor	Best	Restricted
Operational Complexity	Complex	Medium	Simplest
Call Handover Rate	Frequent	Infrequent	None
Building Penetration	Limited	Limited	Very limited
Wide Area Connectivity	Intersatellite links	Good	Cable connectivity
Phased Startup	No	Yes	Yes
Development Time	Longest	Medium	Shortest
Deployment Time	Longest	Medium	Short
Satellite Technology	Highest	Medium	Medium
Transceiver Type/ Gain	Dual-mode/ Omni	Dual-mode/ Omni	Dual-mode/ > 3 dB

REFERENCE

[1] W. L. Pritchard, H. G. Suyderhoud and R. A. Nelson, **Satellite Systems Engineering**, Chapter 3 Prentice Hall, 1993.

ACKNOWLEDGEMENTS

The authors acknowledge the many co-workers throughout COMSAT Laboratories who have contributed to these studies during the last 5 years.